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Analysis of the effect of the implementation of photovoltaic systems like option of distributed generation in Colombia

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ABSTRACT

With the change in States' conception of photovoltaic systems and economies of scale the installation of smaller power plants has been made possible. This has highlighted the importance of producing closely to the consumption centers. The implementation of more adaptable systems is emerging as a viable alternative in the short and medium term. This article will describe the main characteristics of distributed generation relating to renewable energy sources, with primary emphasis on photovoltaics. Additionally, it will present an analysis of the possibility of implementing photovoltaic systems as a distributed generation option in Colombia and its future prospects. Finally we will conclude that the distributed generation from PV could be a viable option for the country.

Contents

1. Introduction

In recent years, the development of alternative sources of power generation has become one of major global priorities, in particular less environmentally polluting renewable sources. Whist fossil fuels will continue supplying a significant fraction of energy demand, with a growing importance of natural gas; energy supply will tend to be more diversified. Options such as wind, solar, renewable biomass, hydrogen and fuel cells will play an important role in the long run and will produce substantial changes in the technological and organizational environment of the global energy system [1,2].

With states' and economies' changes of conception of energy systems, and with economies of scale the installation of smaller

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power plants has been made possible. This has made proximity between production and consumption centers become important again, however now incorporating new technological developments in response to environmental concerns, and with the electric back on the network. The implementation of more adaptable systems, which can be more fully distributed, has emerged as an alternative to provide a higher penetration [3].

In other countries, the use of renewable energies and the introduction of distributing electricity generating systems have been encouraged by governments through different types of incentives supported by environmental policies [4,5]. In Colombia, reduced dependence on fossil fuels and the diversification of the market in order to minimize the risk of lack of supply, coupled with concerns on reduction the negative impacts of energy consumption, have made renewable energies attractive alternatives. Additionally, the possibilities for energy production close to consumption centers and inadequate energy supply in remote and rural areas make distributed generation in an interesting and promising technological option.

In this paper we will deal with the following: first, we will analyze the applications, advantages and disadvantages of distributed generation. Secondly, we will describe the present state of renewable energy. Thirdly, we will provide a study of grid-connected photovoltaic systems in order to evaluate the use of such systems in Colombia and discuss future trends. Finally, the conclusions will be presented.

2. Distributed generation

Distributed generation (DG) represents a shift that is occurring within centralized power generation. Although one might think that is a new concept, it is somehow at the beginnings of electricity generation [6]. Actually, the electricity industry was based on generating electricity where it was needed. Due to the power plants being in the geometric center of consumption, as consumers grew around them, the industry evolved towards centralized generation schemes, as a consequence of population's growth and assets and the demand of services. However, there were technological limitations of DG power generators and their maximum transport by low voltage was 30–57 km.

Over time, electricity generation was structured as it is known nowadays, that is, with AC current and transformers which allow to bring electric power to virtually any point away from the center of generation. Under this way, the concept of "Centralized Generation" was neglected as a result of the location of plants away from places of electrical consumption, although close to the fuel and water supplies.

In the seventies, issues of energety (oil crisis), environmental change (climate change) and electricity demand (high growth) factors around the world raised the need for technological alternatives to ensure, firstly, the timely and qualitative supply of the electric power and, on the other hand the efficient use of natural resources. One of these technological alternatives to generate electricity is to generate electricity as close as possible to the place of consumption, just as they did at the dawn of the electrical industry, now incorporating the modern technology and the network electrical support to offset any additional electric energy purchase or sale requirement.

This mode of power generation is known as in situ generation, dispersed generation, and distributed generation [7].

Therefore the GD can be defined as integrated or segregated use of the generation resources or modular electrical energy storage, as close to the load center, with the option to interact (to buy or sell) with the electrical grid [8].

DG dissemination and promotion success lies in the existence of technologies that allow, for small power, to generate electric power in an efficient, reliable and quality service. These technologies can be divided into the generation and storage as shown in Fig. 1.

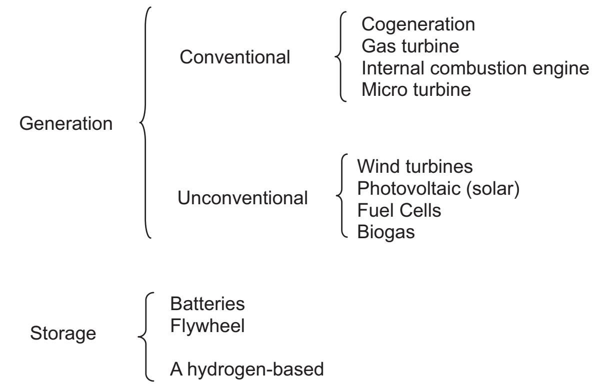


Fig. 1. DG technologies.

2.1. DG applications

The application of various GD technologies depends on the user's individual requirements. The most common technological systems are listed below [9–10]:

a. Base load: The system operates in parallel with the distribution network. It can take or sell part of the energy and uses the network as support and for the maintenance. The system is running constantly and reduces the consumption of electricity network.
b. Provide peak load: It is used to supply electricity during peak periods, thereby reducing peak demand of consumers since the cost of energy in this period is usually the highest.
c. Support to the distribution network: Sometimes, sporadically or periodically, the electricity company or large customers require it to strengthen its power grid by installing small plants, including the power substation, to avoid and resolve congestions due to high demands at different times of the year or network failures.
d. Supply quality: If the quality of the supply is below the needs of the customer, this application provides the required quality eliminating fluctuations.
e. Energy storage: This alternative can be considered as a viable alternative when the cost of using technology is variable or when interruptions are frequent or when using renewable energy sources.
f. Backup: stand-by supply which ensures the uninterrupted electricity supply. Works only when a power outage occurs.

2.2. DG advantages

The DG allows to produce, store and manage the energy in the same place of consumption. This brings many benefits for distribution companies. Within the advantages, it is worth noting the following [11–14]:

a. It avoids or defers investment in transmission and distribution by locating generation close to consumption.
b. Depending on network configuration and the load and generation location, the decentralized energy produced prevents an equivalent amount from being transported over long distances, with the added losses. By the same token, it reduces congestion in transport systems to the final consumer.
c. It improves the supply reliability. It reduces the chances of failures when outages occur in the high voltage transmission lines by decreasing the percentage of its use. This is essential in appli-

cations that require continuous service for health and safety reasons.

d. Reactive power control and voltage regulation in distribution network: One of the ways to regulate the tension using transformers with taps or the known buster. Distributed generation may inject a reactive quantity which improves the distribution network voltage levels.
e. Flattening of the demand curve: distributed energy production may coincide with peak demand, avoiding the use of electrical power from distant power plants that operate only during those hours, at a very high price compared with electricity of the off-peak hours. For example, PV systems have their peak production in hours where consumption is increasing due to the use of air conditioning systems in warm climates.
f. It gives a choice of self supply in areas where network infrastructure does not exist or is very expensive which opens markets in remote areas without access to the mains or with high environmental restrictions.
g. It increases the options of power supply for users.
h. Its location is more flexible due to its small size.
i. In cases of contingency, it is possible to operate the systems provisionally, giving a greater support to the affected region.
j. It allows to minimize the risk due to changes in the price of the energy.
k. It limits the risk and capital exposure due to its size, easiness of location and short installation time.
l. It allows to use cheaper fuels that otherwise would be used as agricultural residues, biogas from landfills, waste heat, etc.
m. Incentives for renewable energy sources: Many renewable generation technologies operate at scales of small generation and can be adapted by the smallest users. This opens a possibility for the use of resources that reduce environmental pollution.

2.3. DG technical barriers and limitations

When interconnecting a small amount of sources of GD in a distribution system, it does not usually affect the operation of the system compared to the strong endorsement that the system upstream of it has. However, when the penetration of the DG becomes significant, the system dynamics can be affected.

In this sense, the DG interconnection analysis is complex, especially taking into account the wide variety of technologies and the typical radial configuration of the distribution networks, which have been designed to operate with power flows only in one direction. Engineers and systems operators will need to rule out some of following challenges when incorporating DG on a large scale [15–22]:

a. System frequency: Deviations from the system nominal frequency are caused by unbalances between supply and demand. The increase in the amount of distributed generation affects the system frequency and these generators have the potential to become “free riders” making the process of control more complicated.
b. Voltage levels: The installed distributed generation changes the voltages profile of the distribution network because of the change in the magnitudes of power flow. Usually the voltages profile will tend to rise, which is not a problem in congested networks with low voltage problems, as would be in the contrary.
c. Protection schemes: As already mentioned, the majority of the distribution networks are configured in radial form, and most of them at split rings. This generates unidirectional flow patterns, and so the protections system is designed accordingly. The installation of distributed generation changes the flow into bidirectional, and so necessarily implying new safety equipment and resizing of the network (grounding, short-circuit, breaking capacity, SCADA systems, etc.)
d. Reactive power: Many DG technologies use asynchronous generators that do not supply reactive power to the grid.
e. Inverters: Technologies such as photovoltaic and fuel cells generate direct current and must be “conditioned” to the network by power inverters and battery systems. The connection of these equipments may generate power quality problems on the network much as the harmonics injection.
f. High cost of installation: A number of technologies have high investment costs compared to conventional technologies. Taking into account the state of art, prices are not yet stable, and highly dependent on production levels and technological developments. The high initial cost is also a disadvantage for small DG systems (residential).
g. Islanding protection is an important security, this is, a condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system. A DG may be feeding a short circuit, thereby generating the possibility of fire or energizing a certain segment of the network, which may cause a risk of death to workers who come into contact with it when not timely advised of the possibility of it being energized. One way of solution is to place protective equipment such as relays (electronic or mechanical) and transfer switches
h. There are technological developments which allow to integrate power electronics in the teams of DG, which gives the possibility of isolation in case of failures in the network. However some distribution companies in the U.S. [23] are reluctant to accept such technology, mainly for lack of knowledge and confidence, requiring the traditional approximation of relays and circuit breakers, which ends up duplicating equipment and causing a considerable overrun.
i. The same situation occurs in regard to power quality in terms of the introduction of harmonics, voltage fluctuations and frequency variations. Although DG equipments have adequate protections against this phenomenon, usually designed according to accepted norms and standards (e.g. IEEE), companies require equipment with which they are familiar, such as over and under voltage relays, and frequency relays, among others [24–26].
j. The connection studies required by companies may end up being a barrier to DG, either by the type and cost of the studies normally done, or by the deadlines they must meet.

Uncertainty costs: Some DG technologies are in development stage, and therefore their costs are not stable, revealing variabilities that depend on the technological development or on the scales of production. The potential investor sees risk factors, especially in technologies that although potentially present environmental advantages but have not yet been examined by his learning cycle.

3. Current status of renewable energy

Renewable energies are defined as those that are inexhaustible, originated or not in the sun, pointing out, that the concept of “renewable” refers to periods of consumption which are not higher than their natural production or generation. Table 1 shows the list of the main sources of renewable energy on the planet and the technologies used to convert it into useful work [27,28].

As noted, one of the main sources of renewable energy is solar radiation, which is responsible for evaporation, wind and photosynthesis, natural phenomenon that directly affect the rains and waves in the formation of fossil fuels like coal, oil and gas, as well as vegetable biomass. Solar radiation is then the energy source on which

Table 1
Main sources of renewable energy on the planet.

Source	Effect	Product	Energy technology	Final objective
Solar radiation	Evaporation	Rain	Hydraulic power	Work done + heat sink
	Wind	Waves	Wind power	
			Wave energy	
	Photosynthesis	Vegetable biomass	Combustion	
		Coal, gas, petroleum	Combustion	
		Biofuels: oil, hydrocarbons, etc.	Combustion	
		Vegetable biomass with high levels of sugar	Ethanol by alcohol fermentation	
			Solar thermal energy	
			Solar photovoltaic energy	
Gravitational attraction	Tides		Tidal energy	
Internal heat	Hot springs	Steam in the surface	Geothermal energy	

most technologies for the production of work and heat were developed, among them the different main energies: hydraulic, wind, thermal and photovoltaic.

Fig. 2 shows the current situation of renewable energies in the world and their contribution to global primary energy in 2008 [29]. During this year, renewable energies accounted for 19%. Within this percentage, the technologies that contributed the most were: traditional biomass, which contributed with 13%. It is primarily used in cooking and heating, and presented a very slow growth in world regions where it is being replaced by modern energy technology. Large hydroelectric power plants contributed about 3.2%, and their growth has also declined in the last decade, mainly due to the increasing difficulty of finding floodplain areas and environmental licensing. Moreover, new renewable energy contributed 2.7% [29].

New renewable energies are made up by small hydroelectric power plants, modern biomass, biofuels and energies like solar, eolic, and geothermal. New renewable energies account with 2.7%, which is mainly used to generate electric power (0.7%), and produce sanitary hot water and heating (1.4%); the last 0.3% are used as transportation fuels, it means they were used as biofuels.

Fig. 3 shows the growing of renewable energies during the period 2004–2009 [29]. For many renewable technologies, such as wind power, growth has accelerated in 2009 in comparison with to the previous four years. Grid connected solar photovoltaic (PV), however, increased the fastest of all renewable technologies, with a 60% annual average growth rate for the five-year period. Biofuels also grew rapidly, at a 20% annual average rate for ethanol and a 5% annual average for biodiesel (reflecting its lower production levels), although growth rates began to decline later in the period. Other technologies (including hydropower, biomass power and heat, and geothermal power) are growing at more ordinary rates of 3%–6%, making them comparable with global growth rates for fossil fuels (3%–5%, although higher in some developing countries).

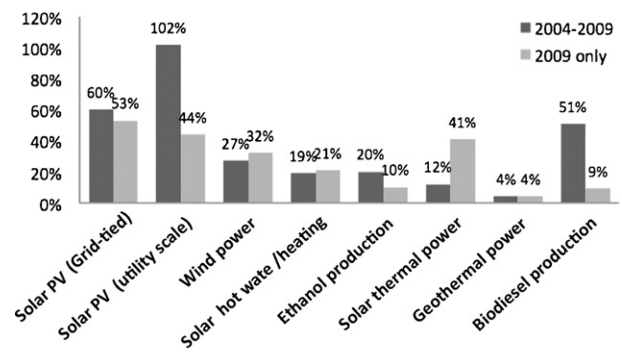


Fig. 3. Growing of renewable technologies during the period 2004–2009. Source: REN21. 2010

Fig. 4 shows the installed capacity of renewable electric power worldwide, discriminating the global regions that contribute the most to this capacity [29].

By the end of 2009, the capacity of renewable power worldwide presented a total of 305 GW, (excluding large hydropower plants), which corresponds to an increase of 22% over 2008. The five countries that contributed to the increase in renewable power capacity in 2009 were China, USA, Germany, Spain and India. In the European Union, renewable accounted for more than 60% of newly installed capacity during 2009, and U.S. wind power alone was the largest

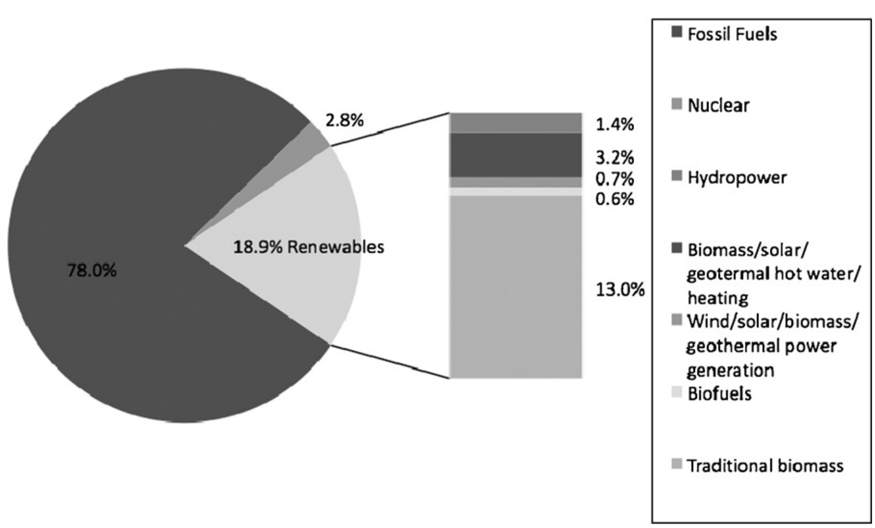


Fig. 2. Participation of renewable energy within the framework of primary world energy.

Source: REN21. 2010

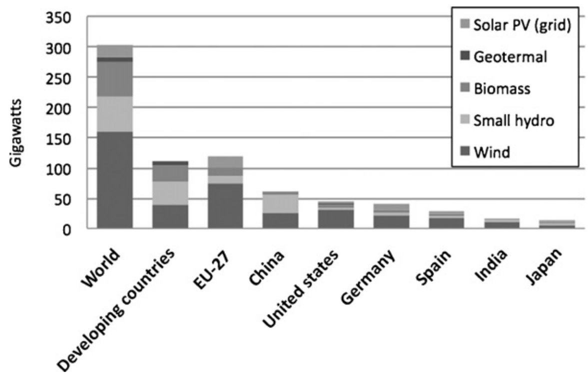


Fig. 4. Contribution to renewable electric power.
Source: REN21. 2010.

source of new capacity additions. China added an estimated 37 GW of grid connected renewable capacity in 2009, for a total of 226 GW.

4. Grid-connected photovoltaic systems (GCPVS)

Currently interconnected photovoltaic systems are being used as a complement to conventional generation in many countries [30,31]. Applications range from small power generation in remote areas in the past 25 years to centralized stations with the capacity of large scale photovoltaic generation. Recently an important stage in the development of GCPVS was reached because PV technology has gone from being useful only in applications in remote areas to being useful also for urban consumers used as an application of distributed generation, where small capacity generation plants are installed in the roofs of buildings or residences within the concept BIPVS (Building Integrated Photovoltaic Systems). A very large amount of residential GCPVS have been installed internationally, so that today's generation with this type of system exceeds that generated independently [32]. Fig. 5 shows the typical configurations of GCPVS centralized and distributed operating systems (BIPVS) respectively.

In GCPVS, the photovoltaic generator is interconnected to the grid through an electronic inverter, a device that converts direct current (DC), generated by array modules, to alternating current (AC). In PVS BIPVS, energy is injected into the grid when generation exceeds consumption at a given moment, and otherwise draws power from it.

From the energy efficient point of view, GCPVS represents the application of photovoltaic solar energy better than other systems; since the generation takes place at the site of consumption (transmission and distribution losses are avoided). There is little loss of processing (inverters typically run in high levels of efficiency and low voltage), and can be used fully due to high grid reliability.

4.1. Operation of a GCPVS

Fig. 6 shows schematically a block diagram of a typical GCPVS. The six functional blocks are described below:

a. Photovoltaic generator.
b. Inverter, responsible for adapting the characteristics of the energy produced by the generator (DC to variable voltage) to those required by the grid.
c. General services panel, or point of common coupling (PCC), where there are protection items to ensure the safety of the grid and the GCPVS itself.
d. Bi-directional meter of AC power.
e. Load, consisting of all those applications that require electricity to work.
f. Electric grid.

PVS works as follows: DC electric power produced by the PV generator is converted to alternating current (AC) by the inverter. The AC generated by the inverter is synchronized with the voltage frequency of the grid. The energy that was not consumed in the same installation site, after passing through the meter, will be injected to the grid. Electricity is consumed near the generation, and losses for transportation are reduced

4.2. Dimensioning photovoltaic systems

The aim of engineering of GCPVS is to maximize the generation of electricity.

The evaluation of the solar resource available at the installation site is the starting point in the measuring of a PV system. This energy source is quantified by the number of hours of sunshine standard (HSS), which corresponds to the average number of hours per day of sun radiation to 1000 W/m^2 (solar radiation standard). The number of HSS is determined by dividing the incident energy in the locality in the form of total global solar radiation, by the value of solar radiation standard.

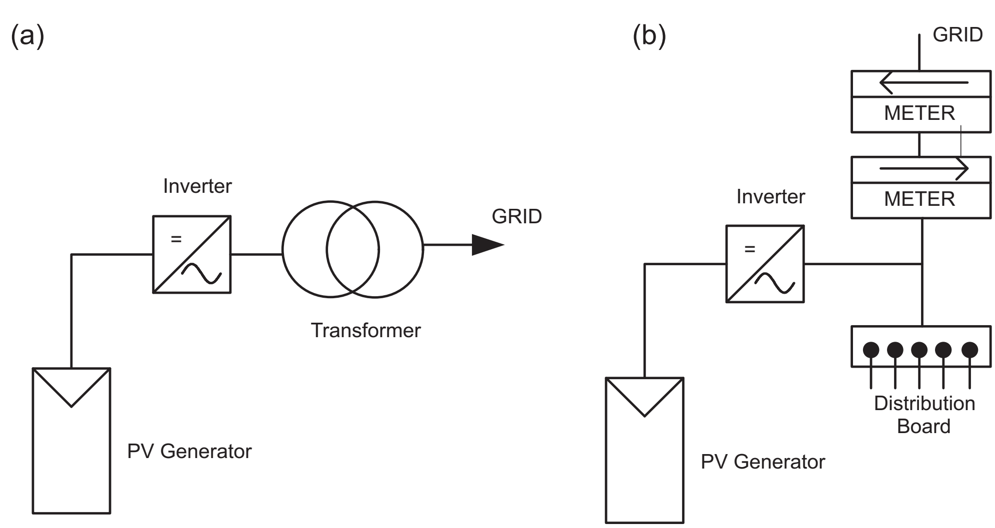


Fig. 5. Configuration of IPVS to operate (a) centralized, and (b) distributed in residential areas.

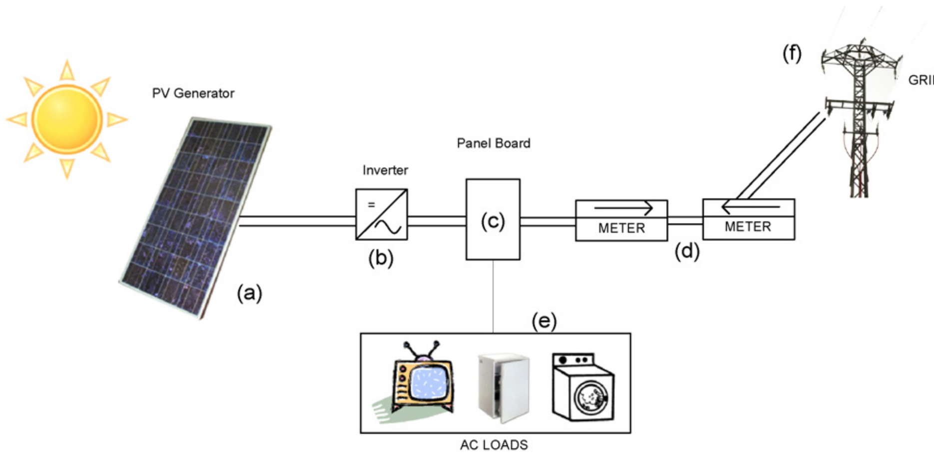


Fig. 6. Block diagram of a grid-connected photovoltaic system.

In the specific case of Bogota, Colombia, the commonly used information is 4 HSS. However, measures of global radiation have been made by the National University (Group of Semiconductor Materials and Solar Energy – GMS & ES) on the terrace of the Physics Department, using their weather station developed in July 2002, show that monthly daily averages of HSS in Bogota range from 3, 01 in April to 4, 26 in January (Table 2).

The dimensioning of a photovoltaic system (autonomous or interconnected) is carried out by energy, not power, as it is usually the case in an electrical installation. GCPVS are dimensioned by determining how much energy (in kW/h) must be produced by the system during a period, usually one year. There are two trends in the methodology used to measure a PVS:

The first is to find the optimum dimension of a GCPVS that, in a normal year, would ensure the supply of electricity demand for a family or the community where this is going to be located. This consumption is easily verified by reviewing the bills from the electric company or the meter readings during the year.

The second is to dimension the facility the proper size to cover one's annual electricity consumption. This criterion is often used in countries where there are regulatory norms that give a special bonus to energy generated in a photovoltaic way. In this case, what is sought is to recover the initial investment of the installation in a short time, using the bonus received.

4.3. Dimensioning of GCPVS components

4.3.1. Photovoltaic generator

The generator is composed of a group of modules that are series or parallel circuits interconnected depending on the investor input voltage. The peak power calculation which the PV generator must supply to meet a specific demand is calculated by the following equation:

$$P_{\mathrm{GFV}} = \frac{\sum_{i=1}^{12} \frac{E_i}{\mathrm{HSS}_i \cdot N_i \cdot \mathrm{PR}}}{12} \tag{1}$$

where E_i is the averaged monthly production of solar electricity (in kWh/month) defined by the user. This value of E_i is the expected power in the year divided by twelve. HSS is the monthly average daily hours of standard solar radiation in the locality, NI is the number of days in the month concerned and PR is the performance factor, which is introduced to achieve greater reliability in a PV system operation. This factor allows to measure the GCPVS to compensate the reduction of the capacity specified by the manufacturer (due to several factors such as effects of temperature, dust, losses due to bad connections, etc.). This performance factor is used so that the system is generally in a value around 10–20%. As a result, PR has usually has values between 0.7 and 0.9.

4.3.2. Inverter

To size the inverter the relative size generator–inverter is defined in a way that overshoot the photovoltaic generator. A factor called dimensioning factor of the investor is specified by the relation:

$$F_{\mathrm{DI}} = \frac{P_{\text{máxima,Inversor}}}{P_{\text{nominal,Generador}}} = \frac{P_{\mathrm{max,I}}}{P_{\mathrm{max,G}}} \tag{2}$$

The F_{DI} is determined depending on the geographic situation (latitude, longitude), the setting of the system (roofs, facades, open field) and environmental conditions of installation place. Generally, the F_{D} takes values between 0.8 and 1 [10,11].

The inverter efficiency depends of the supplied current to the load, being highest under operating conditions such that the power delivered to the load is equal to the rating of the inverter. Efficiency can reach 97%, but if the inverter provides less than the nominal power, efficiency decreases.

4.4. Study of the energy performance of GCPVS

Energy efficiency of GCPVS depends critically on the available solar resource at the site. Therefore, to compare the performance of systems installed in different locations it is necessary to separate their operation from environmental conditions. For it, energy efficiency parameters characteristic of the system are defined, which were established by the program Photovoltaic Power Systems of the

Table 2
Monthly daily averages of HSS, obtained from global solar radiation measurements carried out on the terrace of the Physics Department in the National University in Bogota, since 2002 [33].

Month	HSS
January	4,26
February	4,54
March	3,54
April	3,01
May	3,08
June	3,26
July	3,48
August	3,53
September	3,65
October	3,30
November	3,33
December	3,67

International Energy Agency (IEA) and are described in IEC 61 724 [34]. These have been adopted by the international scientific community and are usually reported in monthly and/or annual periods. The three most important parameters are:

Final yield (Y_F), defined as the useful energy produced by the system in a certain period of time (E_{FV}, τ) divided by the rated dcgenerator installed:

$$Y_F = \frac{E_{FV,\tau}}{P_{nom}} (\text{kWh} \cdot \text{kW}_p^{-1} \leftrightarrow \text{h}) \quad (3)$$

This parameter normalizes the energy produced to the size of the system. In addition to the easy determination, using the dc power offers advantages such as comparing systems of different sizes, from any ac power, environmental conditions different from standard environments or with different module assemblies. For example, if performance is measured with respect to the ac power, two systems could have the same Y_F, yet having significant differences in the efficiencies of investment losses or other mechanisms.

Reference yield (Y_R), defined as the ratio of solar radiation incident on the generator over a period of time (G_{inc}, τ) and radiation in standard conditions ($I_{STC} = 1\,\text{kW/m}^2$).

$$Y_R = \frac{G_{inc}}{I_{STC}} (\text{h}) \quad (4)$$

Global performance ratio (PR), which relates to the useful generated energy of the system which is theoretically available. It is a parameter independent of the installation size (power), and also for its location (is affected by temperature changes). Lets compare the performance of different systems, with respect to use of solar resources available:

$$\text{PR} = \frac{Y_F}{Y_R} \quad (5)$$

This dimensionless parameter quantifies the overall effect of losses on the inverter efficiency, wiring, junctions, mismatches, shading, component failure, degradation, etc.

PR is a parameter that does not represent an amount of produced energy, because a low PR system in a high radiation could produce more energy than a high PR in a low solar radiation. On the other hand, the PR is useful for identifying the existence of problems but not the cause.

4.5. Overview of photovoltaic generation

Since the energy crisis of 1973, PV technology has made significant progress. For many years now, the photovoltaic (PV) market has been growing with double-digit growth rates.

Almost the totality of the solar cells sold today are made of silicon, 90% of them of crystalline silicon, of which 40% of single crystalline silicon and 50% of multi-crystalline silicon [36]. As shown in Fig. 7 [35], the cost of PV modules in the last four decades has reduced significantly and in the last couple of years the market has also grown quite rapidly. Near term market growth of bulk silicon and thin film solar cells are shown in Fig. 8.

A well accepted economic law tells us that most goods reduce their price by a constant factor every time that their cumulated production is doubled. This factor is called the learning factor and is constant as far as the technology does not experience a drastic change. Conversely we may define as a drastic change the one that inflects the learning curve. For PV modules the learning factor is 0.83. The modules become 17% cheaper any time that their cumulated production is doubled. This is a modest learning curve, well below, for instance, that of the microelectronics. On the other hand we call demand elasticity the logarithmic derivative of the market with respect to the price.

The combination of the two preceding equations leads to laws for the evolution of the yearly markets and the prices [36]. Past market evolution may be explained using a constant value of the demand elasticity. However, this elasticity cannot stay constant forever because the market curve presents an unrealistic vertical asymptote. Sooner or later the elasticity has to decrease.

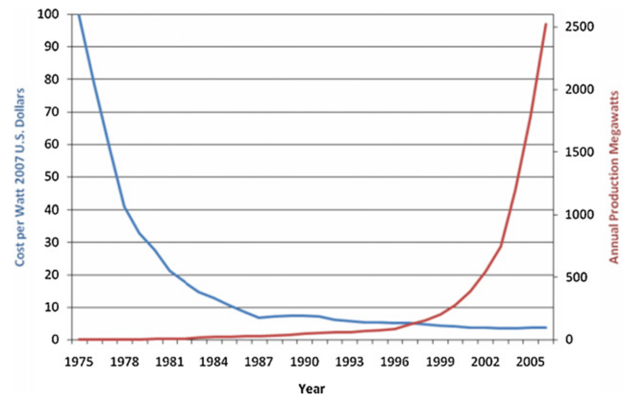


Fig. 7. World PV production and cost per watt in the last about 30 years Source: [35].

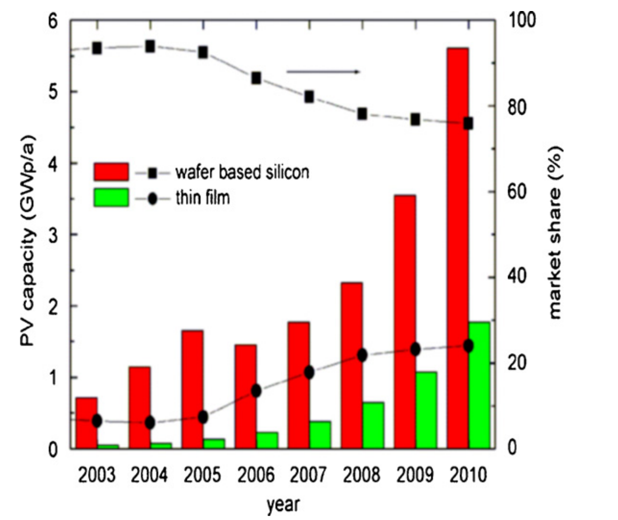


Fig. 8. Production capacity until 2010 in GWp/a and market share for wafer-based silicon and thin-film PV technology.
source [37].

The projected break up of various thin film PV technologies is shown in Fig. 9 [38]. Recent double digit growth in PV market is not due to any major breakthrough in PV technology, but it is due to the subsidies offered by various governments, especially by the European countries and Japan. As an example, in 2006 European Union provided subsidies of $4.7 Billion for generating electricity by renewable resources (mostly PV) [39].

More of 80% of PV modules current global production corresponds to mono and polycrystalline silicon technology while thin film technology contributes around 12% (see Fig. 10) [40]. In thin film technology, three photovoltaic materials currently allow to manufacture solar cells produced industrially: amorphous silicon (a-Si), CdTe and CuInSe2 (CIS). Currently efficiencies of 25% are achieved with the triple type junction panels [41].

5. Photovoltaic systems in Colombia

The development of photovoltaic systems in Colombia has been focused mainly on the rural sector. In the rural sector the high generation costs incurred primarily in fuel prices and costs of operation and maintenance in remote areas. This fact makes solar

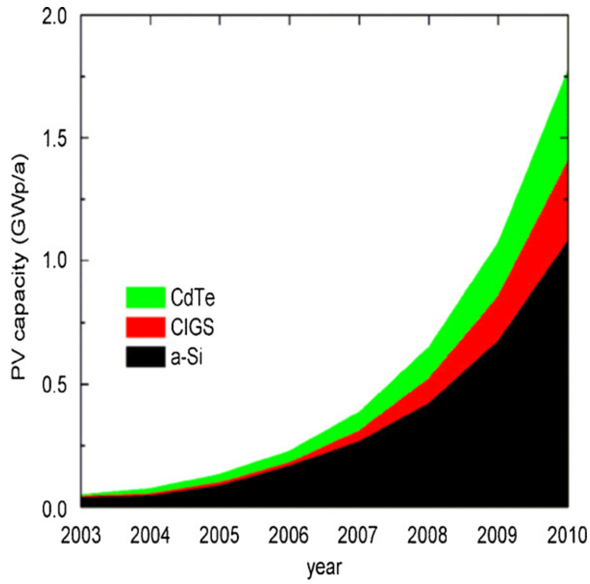


Fig. 9. Production capacity until 2010 in GWp/a for thin-film PV technology [38].

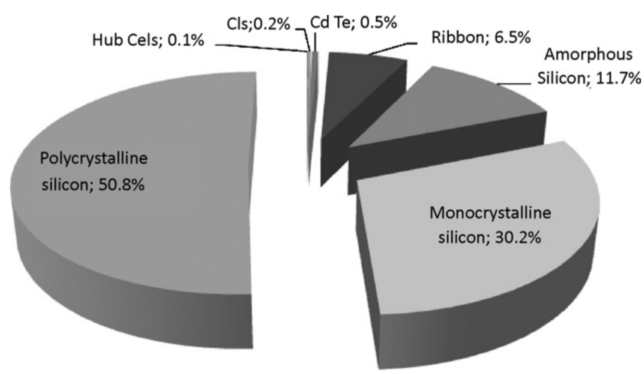


Fig. 10. Contribution of several technologies of photovoltaic modules to the worldwide market.

generation more reliable and economic in long-term [42]. In 1979, TELECOM considered its use for the Rural Telecommunications Program and bought the first systems. This program installed small photovoltaic generators 60 Wp (Wp: Watt peak) for rural radio telephones and 2950 systems were installed in 1983. The program continued installing these systems and quickly climbed to 3–4 kWp systems for satellite antennas. Many companies began to install solar systems for their telecommunications services, currently used in microwave repeaters, buoys, remote stations, military bases, among other applications. These systems are now essential for rural telecommunications in the country.

Moreover, in recent years, PV systems has been installed in rural electrification programs, with strong state funding, currently using resources like FAZNI (Fondo de Apoyo Financiero para la Energización de las Zonas No Interconectadas). These small systems (50–70 Wp) provide power for lighting, radio and TV, covering the basic needs of the peasants. The current cost of this system is around 1200–1500 U.S. $, mainly affected by the high costs of installation in remote areas. A project entitled "Construcción y puesta en operación de 125 kW de energía solar fotovoltaica para diferentes localidades de las zonas no interconectadas" is currently developing for the Department of La Guajira (Municipality of Uribia) and Department of Bolívar (Cartagena) [43]. The objective is to implement a pilot power generation microgrid with renewable and conventional sources, to evaluate its social, economic and environmental impact, and explore the possibility of replicate this experience. The responsible entity for the implementation of this project is the IPSE (Instituto para la Promoción de Soluciones Energéticas) that currently leads the State's actions in the Colombian countryside energization.

The trend of energy policies to increase the energy supply from renewable sources in Colombia can be synthesized in Law 697 of 2001 or commonly called Law URE (Rational Use of Energy) and Decree 3683 of 2003. The first seeks to establish the principles governing this issue and the second to establish an institutional structure. This Law and this Decree, while necessary, have not been sufficient to promote such sources as evidenced by the reality of the achievements since its enactment.

It is therefore necessary to formulate a program to develop renewable energy sources in order to diversify the national energy market and have more options in the future energy supply. The depletion of fuel fossils, which are highly polluting, is predicted. Thus supplying of power to areas, that are isolated or difficult to access, is necessary.

6. Conclusions

The use of renewable energy on the planet is growing exponentially. This is mainly due to environmental awareness in politics and to new society energy needs. The direct effects of this growth are the fall in component prices and the improved technology associated. This fact can be exploited to diversify the energy market and to provide electricity to remote and isolated areas where nearly one million families in Colombia lack a reliable electricity service.

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